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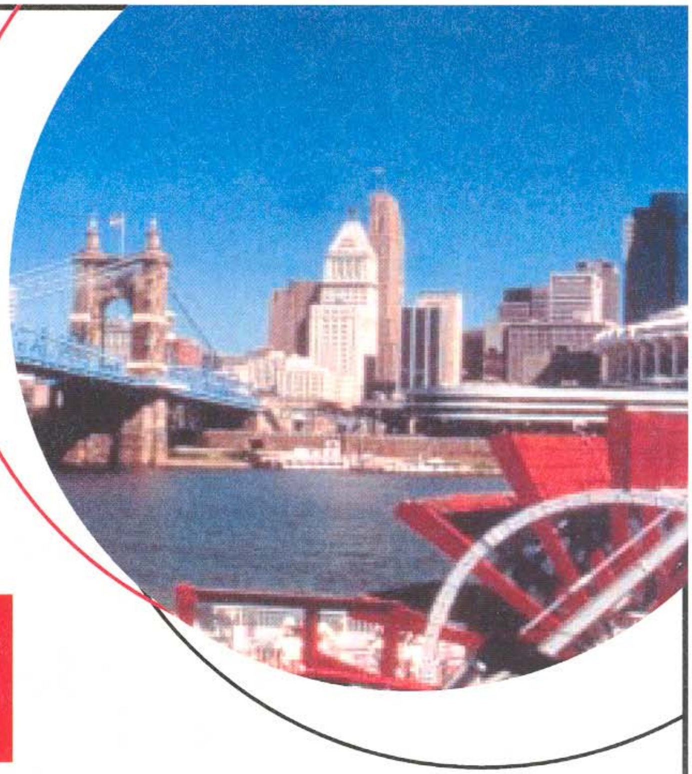
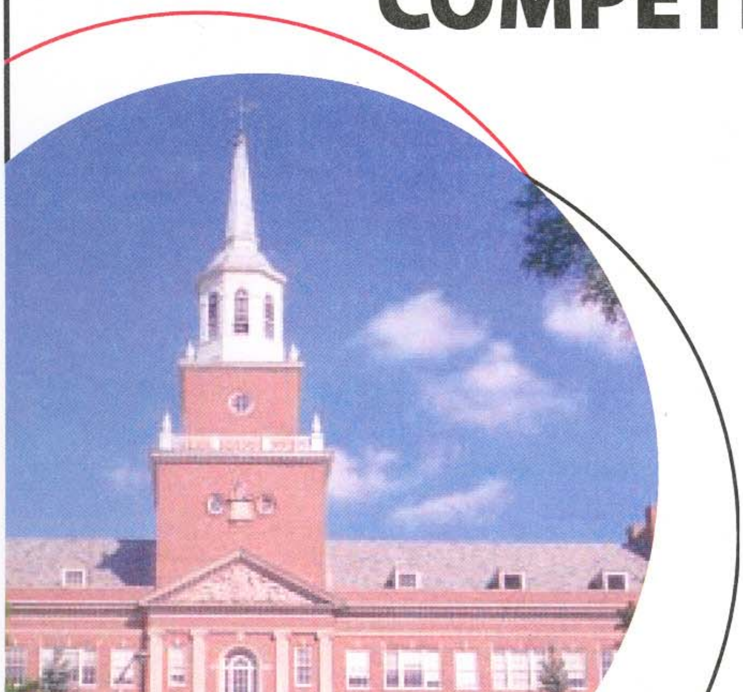


10th International Symposium

CONSTRUCTION INNOVATION *and* GLOBAL COMPETITIVENESS



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Economic Approaches to Homeland Security for Constructed Facilities

Keynote Address

Presented 11 September 2002
at
University of Cincinnati
Cincinnati, Ohio, United States
at
Tenth Joint W055-W065 International Symposium on Construction Innovation and Global Competitiveness

Dr. Harold E. Marshall
Office of Applied Economics
Building and Fire Research Laboratory
National Institute of Standards and Technology
harold.marshall@nist.gov

ABSTRACT

The 11 September 2001 terrorist attack on the New York World Trade Center (WTC) Complex and the Pentagon changed dramatically the way buildings, industrial facilities, and infrastructure will be designed, sited, and managed in the United States. The magnitude of losses has forced the owners and managers of constructed facilities, both private and public, to include in their decision-making the possibility of terrorist attacks on their property. This paper presents economic models of how to choose in a financially responsible manner among protective strategies designed to reduce the expected value of terrorist-induced damages. The life-cycle cost and net savings models help the user choose the cost-effective level of investment in a given protective strategy (say hardening the building against fire and explosives). They also help users choose the optimal combination of protective strategies (say hardening the building; upgrading the heating, ventilating and air conditioning system against biological contamination; or increasing security to prevent terrorist encroachment), when each strategy in itself is cost effective, but inadequate funds preclude implementing all cost-effective strategies. The paper proposes additional research needs on the treatment of interdependencies in protection measures and the optimal timing of investments for protection. It describes spillover benefits from protection against terrorism, why most resources will be allocated to the protection of existing buildings, and how decision-making perspectives regarding protection against terrorism may differ between private and public facility managers. Finally, it describes desirable characteristics of a software product that could be used to implement the described economic models. Expected economic impacts of such a product will be a decrease in the expected value of terrorist-induced losses (i.e., a decrease in deaths, injuries and damages from terrorist attacks); a decrease in damages and injuries stemming from other disasters that affect buildings--fire, floods, and high winds; and additional spillover benefits from reduced burglary and vandalism.

INTRODUCTION

The 11 September 2001 terrorist attack on the New York World Trade Center (WTC) Complex and the Pentagon changed dramatically the way buildings, industrial facilities, and infrastructure will be designed, sited, and managed in the United States. The two plane crashes at the WTC site ultimately cost the lives of 2 823 persons (Washington Post, “Nation in Brief”). Casualties included building occupants, firefighters, police officers, and airplane passengers and crew. The plane that hit the Pentagon caused 125 occupants of the Pentagon and 64 passengers and crew to lose their lives (New York Times). The hijacked plane that crashed in Pennsylvania took the lives of an additional 44 passengers and crew (Washington Post, “News of the Attacks”).

The economic losses inflicted by the four hijacked planes included uninsured replacement costs of infrastructure and property, disruptions to business, loss of income, insurance payments, and wealth erosion in the stock market. The insured property loss of the 9/11 terrorist attack is estimated at $19 billion dollars, over 20 times the insured loss of the next most costly terrorist event in the world, a bomb in London in 1993, and over 150 times the insured loss of the Oklahoma City bombing in the United States in 1995 (Hartwig, 15).

Total insured losses, including life, liability, and workman’s compensation losses, are estimated for 9/11 to total over $38 billion (see Figure 1). This is over 2 times that of the next biggest catastrophe in the world, Hurricane Andrew in 1992 (Hartwig, 18).

Total economic impacts of $151 billion have been estimated elsewhere for September 11—$18 billion for increased workplace security; $15 billion for information technology security; $65 billion for logistical changes to maintain the supply of goods and services; $12 billion for travel safety; $35 billion for insurance and liability; and $6 billion resulting from employee absenteeism (Bernasek, 106).

New York City alone is estimated to have suffered losses of $83 billion from the 9/11 attack: $39 billion in lost output, $30 billion in capital losses, and $14 billion in clean-up and other expenses (Hartwig, 119).

The magnitude of these combined losses have forced the owners and managers of constructed facilities, both private and public, to include in their decision making the possibility of terrorist attacks on their property. To protect constructed facilities and occupants from possible terrorist attacks, decision makers need tools to (1) identify vulnerable targets among the inventory of constructed facilities and to (2) choose in a financially responsible manner among protective strategies for reducing injuries, loss of life, and expected damages to constructed facilities.

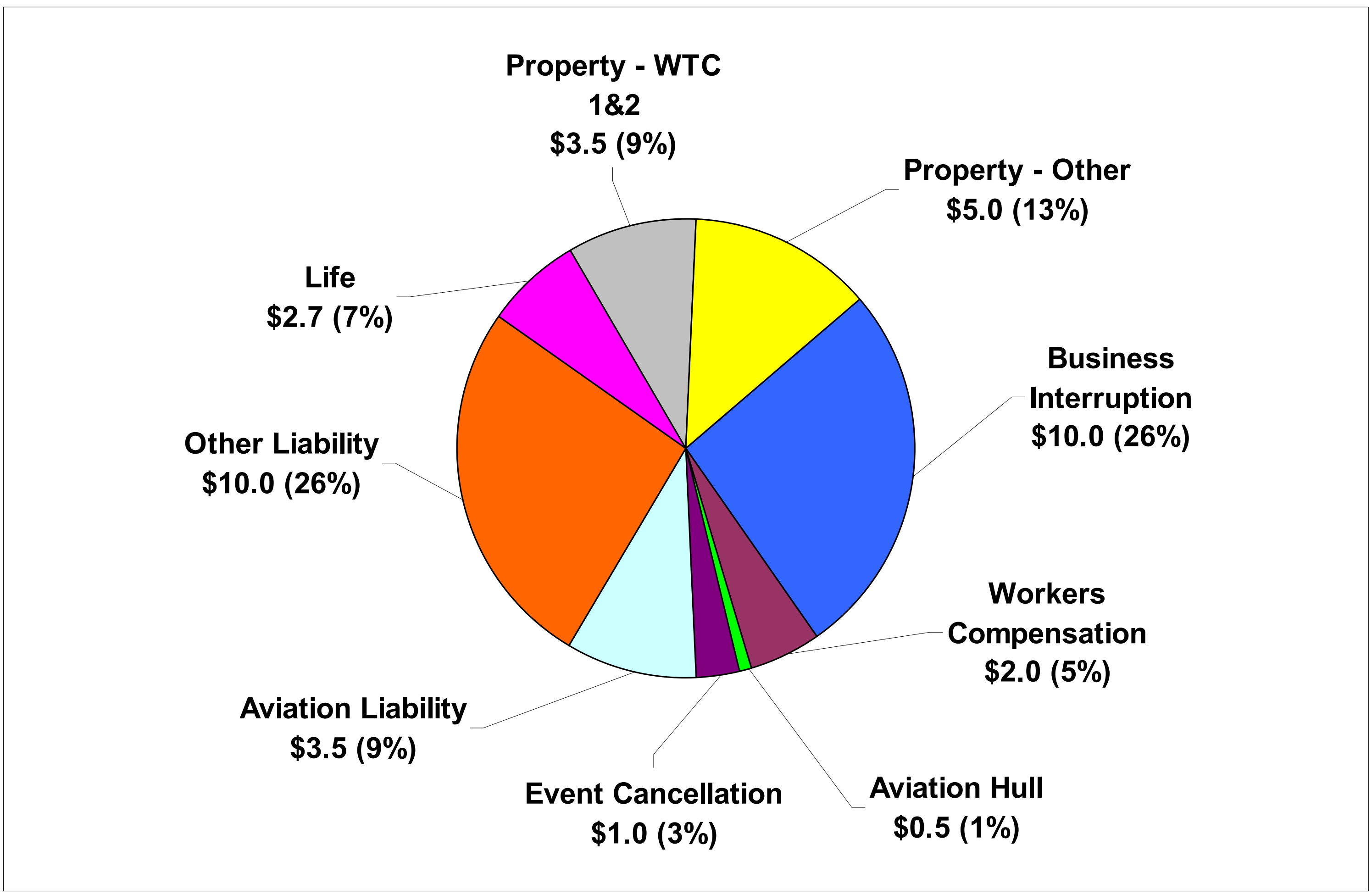

Figure 1 Estimate of Insured Losses in billions of dollars (Hartwig, 14).

PURPOSE

This paper focuses on the tools of the second type: economic models of how to choose in a financially responsible manner among protective strategies designed to reduce the expected value of terrorist-induced damages. The models help the user choose the cost-effective level of investment in a given protective strategy (say hardening the building against fire and explosives). They also help the user choose the optimal combination of protective strategies (say hardening the building; upgrading the heating, ventilating and air conditioning system against biological contamination; or increasing security to prevent terrorist encroachment), when each strategy in itself is cost effective, but inadequate funds preclude implementing all cost-effective strategies. The paper addresses two research needs: the treatment of interdependencies in protective measures and the optimal timing of investments for protection. It describes spillover benefits from protection against terrorism, why most resources will be allocated to the protection of existing buildings, and how decision-making perspectives regarding protection against terrorism may differ between private and public facility managers. Finally, it describes desirable characteristics of a software product that could be developed to implement the described economic models. A discussion of the impacts of using such software concludes the paper.

CONSTRUCTED FACILITIES AT RISK

Constructed facilities as defined in this paper are divided into three classes: **infrastructure**, such as transportation, water resource management, and energy delivery facilities; **non-residential buildings**, such as offices, education, and mercantile buildings; and **industrial buildings**, such as oil refining, chemical manufacturing, and power plants. Figure 2 presents a detailed classification of constructed facilities that could be considered at risk of terrorist attack. Although residential buildings are constructed facilities, they are not included here. While some are large enough to be a terrorist target, most residential structures have a relatively low number of occupants and value of contents.

Some statistics on the number of infrastructure and building types, along with their size, give some indication overall of structures possibly at risk in the United States. For example, there were 587 755 bridges in 2000. There were 18 345 civilian airports in operation in 1997, and there were 104 nuclear power plants in 1999 (US Census Bureau, 581, 671, 677). But the largest number of structures from Figure 2 is in non-residential buildings. The United States has 4 ½ million existing units, containing 5 ½ billion square meters (59 billion square feet). Table 1 shows how these are categorized by building use.

Clearly building owners cannot afford to invest in terrorist protection for all of these structures. But some will be more at risk than others. Larger, more populated structures would likely be more at risk than smaller establishments. Facilities that would yield collateral damages, like nuclear power plants that could release radiation, would likely be more at risk than conventional plants. Large, prominent, famous, showcase, monumental, and public structures would likely be more at risk than typical structures. Given that a structure is determined to be at risk, and given the identification of alternative protective measures, building owners need tools to help them identify cost-effective protective measures within their budgets.

Infrastructure			
	Transportation		
		Bridges	
		Roads/Highways	
		Railroads	
		Canals/Waterways	
		Transshipment Facilities	
			Airports
			Rail Stations
			Marine Facilities
	Communications		
	Water Resources Management		
		Dams and Reservoirs	
		Levees and Locks	
		Water Treatment	
		Waste Water Treatment	
		Potable Water Distribution	
	Energy Delivery		
		Electricity	
		Natural Gas	
		Oil	
Non-residential Buildings			
	Office		
		10 or More Floors	
		Less Than 10 Floors	
	Education		
	Health Care		
	Mercantile and Service		
	Other		
Industrial			
	Oil Refining and Storage		
	Oil and Natural Gas Production		
	Chemical Manufacturing		
	Metals Refining/Manufacturing		
	Consumer Products Manufacturing		
	Pharmaceuticals Manufacturing		
	Electronics Manufacturing		
	Electricity Generating Power Plants		
		Coal-Fired	
		Hydroelectric	
		Nuclear	
		Other	
	Pulp and Paper Manufacturing		
	Other Manufacturing		
		Automotive	
		Aircraft	
		Miscellaneous Equipment and Components	

Figure 2 Proposed Classification of Constructed Facilities

Table 1 Number and Size of Non-residential Buildings: 1995 (US Dept. of Energy, 56)

Building Characteristics	Office	Education	Health Care[a]	Mercantile/ Service	Other[b]	All
Number of Buildings (Thousands)	705	309	136	1 289	2 140	4 579
Building Floorspace in m^2 (Millions)	973	719	284	1 182	2 301	5 459
Building Floorspace in ft^2 (Millions)	10 478	7 740	3 056	12 728	24 770	58 772

[a] "Health Care" includes skilled nursing and other residential care facilities (nursing homes).
[b] "Other" includes all other buildings and vacant buildings.

CBRE THREATS

Facility managers face the four terrorist threats described by the acronym "CBRE." The C stands for chemical; the B for biological; the R for radiological; and the E for explosive. These threats can be employed in a package, as in a "dirty" bomb that provides radiological contamination and explosive force. Or, they can be delivered singly, as in a biological agent release.

A manager of a constructed facility who is faced with minimizing the combined or total CBRE threat to a facility has multiple threat mitigation measures to choose from. Some measures will provide protection against just one kind of threat. Others provide protection against more than one threat. Improved air filters, for example, could clean air contaminated by both biological and chemical agents.

The economic challenge is to select for any given budget that combination of protective measures that will yield the greatest net benefits from damage reduction, lives saved, injuries averted, and business preservation.

PROTECTIVE INVESTMENTS AGAINST LOSSES

Facility improvements through enhanced design, technologies, and operating practices can be used to protect the owners and occupants of constructed facilities against the losses from terrorist attacks. Improved designs result in structures that are less vulnerable to attack, thereby reducing the likelihood of both personal injury and property losses. These design improvements apply both to the construction of new facilities and to the retrofit of existing facilities. Examples are the installation of barriers to keep traffic away from a structure and the siting of facilities in isolated areas to prevent the clandestine or anonymous approach of terrorists. Threat reduction technologies would include bulletproof glass, fire-resistant materials, and enhanced security systems. Improved operating practices would include the use of more and better trained security personnel and tighter monitoring of persons admitted to a facility.

Insurance and incentive programs also affect life-cycle costs of protection. Purchased insurance transfers the owner's risk of property damages and personal claims to another party.

While it does nothing to protect the building owners and occupants from a terror attack, insurance does cover some of the costs of such an attack. Self-insurance, a common practice among governments, can also be substituted for protective measures. Insurance will be attractive to owners in the cases where expected costs of damages plus investments in security for protection against a given terrorist event cost more than insurance coverage for protection against that same event.

Incentives are financial arrangements that can be used to encourage a specific behavior. Insurance companies, for example, might provide as an incentive the reduction of insurance premiums for facilities that invest in designs and technologies that reduce the likelihood of a terrorist event damaging that facility. An example of a government incentive is allowing extra writeoffs on taxes for new technology investments for protective measures. Another example of a government incentive is the availability of government cost-sharing funds to induce private investment in protection.

LIFE-CYCLE COST MODEL

Equation 1 is a life-cycle cost (LCC) equation for computing total life cycle costs of alternative levels of terrorist protection for any given facility improvement.

$$\sum_{t=0}^{N}((C1_t + C2_t + C3_t - B1_t - B2_t - B3_t)/(1+i)^t) + I \tag{1}$$

where N = total number of discounting periods in the study period,
$C1_t$ = expected value of losses from terrorist attack,
$C2_t$ = costs associated with a given protective investment in time period t, excluding initial investment costs,
$C3_t$ = insurance premiums associated with a given protective investment in time period t,
$B1_t$ = spillover benefits unrelated to terrorist damages, such as reduction in workdays lost from improved air quality,
$B2_t$ = benefits from tax savings or government cost sharing associated with a given protective investment in time period t,
$B3_t$ = expected value of insurance payoffs associated with a given protective investment in time period t,
i = discount rate, and
I = initial investment.

Equation 1 sums, for any given type and level of protection, over a prescribed study period, the total discounted LCC of a given investment in protection and the expected value of all losses from a terrorist attack. Finding the LCC of one level of protection by itself is not sufficient, however, to make economic decisions. The LCC of each level, scale, or design must be calculated and then compared to alternatives to determine which level of investment has the lowest LCC for that type of protection.

Take as an example the decision as to how much to invest in the installation of barriers to keep terrorist truck bombs away from a structure. Start with a base case where no barriers are used. Adding barriers could, when compared with the base case, lower the expected value of losses from terrorist attack (lower $C1_t$), cost more to maintain (raise $C2_t$), reduce insurance premiums ($C3_t$), raise benefits unrelated to terrorism (e.g., reduce burglaries); bring more tax savings and cost sharing (raise $B2_t$), but cost more money up front (raise I).

To find the efficient level of investment in the barriers, compute for each increasing level of protection the total LCC. If barriers are expected to reduce expected value losses more than they cost, total LCC will decline. At some point, the incremental investment in barriers will begin to cost more than the expected incremental value of losses averted plus other benefits. The cost-effective level of barrier protection will be the one with minimum total LCC.

This same LCC model allows the facility owner to evaluate the efficient level of investment in security systems; fire and bomb resistant materials; heating, ventilating, and air conditioning systems that protect against biological and chemical contaminants; and security personnel.

It is recognized that data to compute $C1_t$, expected value of losses, are difficult to determine. But implicit evaluations of that loss are made every time investments to protect against terrorist damages are made. Having an explicit, formal expression of how these losses can be considered in selecting levels of investment will lead to more cost-effective investments in homeland security.

OPTIMAL COMBINATION OF PROTECTIVE STRATEGIES

To arrive at the optimal combination of various protective strategies, owners and facility managers have to find that combination which maximizes net benefits of protection subject to the owner's budget limitations.

Let us suppose that a facility manager has been allocated a fixed budget for protecting an office building. Barriers, special air filters and controls, and additional security staff are all viable measures for protecting the facility. Furthermore, none of the protective measures is mutually exclusive with the others. That is, doing one does not preclude doing the others.

If each of these three protective measures is considered at its optimal level of investment, as determined in Equation 1, and if strong interdependencies in benefits do not exist between the measures, then the optimal combination would be found by maximizing the following expression:

maximize $$\sum_{i=1}^{n} NS_i X_i \tag{2}$$

subject to: $\sum_{i=1}^{n} I_i X_i \leq L$; and

$NS_i > I_i$

where $X_i = 0$ or 1 $i = 1, 2, \ldots, n$ protective measures

NS_i = present value of net savings (expected value of loss reduction and other benefits achieved through measure i less present value of all non-investment costs associated with *i*,

I_i = initial investment cost for measure i at the base time, and

L = budget constraint.

In the special case where the budget constraint is large enough to fund more protective measures than are individually economically efficient, optimization requires using less than the full budget amount.

In practice, interdependencies often do exist among alternatives. That is, undertaking one protective investment will affect the benefits or costs associated with another protective investment. For example, expected loss reductions would be less for any given investment in security staff if barriers to entry were also increased. That is, having more barriers in place reduces the probability of a threat reaching its target and thereby the expected damages to be averted by having extra security staff. Thus a more powerful tool to account for these interdependencies is needed.

RESEARCH NEEDS

To account for interdependencies, an analyst could compute the NS for every combination of protective measures at every scale of investment within the budget constraint. In practice, however, this would be overly expensive and time consuming. The building community needs a more practical technique that allows the user to simultaneously consider interdependencies when choosing the optimal combination of protective strategies for homeland security. Operations research techniques, such as dynamic programming, show promise in handling these interdependencies in an efficient manner. (For more information on dynamic programming, see Nemhauser). The goal is to find a practical approach that requires fewer computations than would be required to calculate net savings for every possible combination of protective measures.

A second research need is in the modeling of optimal investments over time. Facility managers typically receive periodic (usually annual) budgets for operations and maintenance. Rehabilitation, expansions, and major repairs generally require special justification and often come from a capital or investment budget. Funds for protection against terrorism could come from either type of budget. Big investments against terrorism for new structures are straightforward in the timing of investments. A new monumental public building, for example, might be funded sufficiently up front to optimize protection. Funding incremental investments over an existing project's life is more difficult. What you invest in during the initial years affects the impact and cost of additional investments in the out years. For example, typical private and public sector buildings are unlikely to receive sufficient funds for significant protection in any one year, leading to the problem of how to achieve the optimal portfolio of protective investments when expecting an uncertain series of small annual budgets for protection spread over multiple years. Thus facility owners and operators need a tool that helps choose protective measures that can be built upon cost effectively over time and provide opportunities for implementing new technologies for protection as they become available.

Choosing optimal protective measures over time is complicated by uncertainty regarding how protective measures will work, what new technologies will become available, the value of protecting the facility and contents over time, and how the risk of terrorism will evolve over time. Doing a conventional economic analysis as described in Equations 1and 2 will often rely on data that are uncertain. To best protect their facility within the available budget, facility managers need a tool that considers these uncertainties when making decisions over time. Options analysis shows promise in dealing with these uncertainties. (For more information on options analysis, see Trigeorgis). It provides the user a tool that accounts for flexibility in a phased approach to selecting measures for protection. And it measures the value of having options for changing direction in terrorist protective measures over time.

SPILLOVER BENEFITS

Designs that resist CBRE threats yield other benefits that might not be apparent. These other "spillover" benefits can be critically important in the benefit-cost calculus of deciding if such protection is cost effective. For example, structural designs that are bomb and impact resistant may also be more resistant to high winds and earthquakes. Glass that does not fail or shatter at high heat will be safer in an accidental fire situation. Filters in HVAC systems that can scrub biological contaminants will also raise the general air quality of a structure on a daily basis, thereby yielding reduced workdays from sickness and greater productivity of the occupants. These spillover benefits are shown in equation 1 as $B1_t$. They reduce life-cycle costs and make a threat protective measure more cost effective than it would be if the spillover benefits were not counted.

NEW OR EXISTING STRUCTURES

Designers of terrorist protective measures have some advantages when dealing with new structures as compared to existing structures. First, changes in design features, material selections, and siting/relocation are much more costly when retrofitting than when made at the design stage for new construction. Second, new construction funds (i.e., capital investment funds) come via a different budget route than do annual operational funds. Large investments for terrorist protection in a new structure are a small part of the total construction budget and are thus less obvious and vulnerable to cuts in new construction as compared to existing structures. Finally, spillover benefits from protection against other hazards can be easily identified in new designs, making it easier to justify new investments in terrorist protective measures in new structures as compared to existing structures.

There are, however, many more existing structures—and corresponding potential terrorist targets—than there are new structures coming on line. Thus the opportunities and need for protection in existing structures is much greater in existing than in new structures. For this reason, there will likely be more resources devoted to the protection of existing structures.

PRIVATE VERSUS PUBLIC MODEL

Most variables affecting economic decision making for terrorist protection are similar for governments and private companies. Incentives and insurance, however, are generally different. Governments make incentives available to private companies to encourage desired behavior. Thus cost sharing or tax writeoffs, as examples, are incentives from a government body that benefit a private company. Incentives affect private companies' bottom lines and therefore choices. $B2_t$ in equation 1 represents these benefits that accrue to a private company.

On the other hand, federal government agencies do make grants to other federal agencies and to state and local governments. These grants could be for homeland protection. And of course Congress can always appropriate money to agencies for homeland protection. To the recipient agency, such grants and allocations reduce costs of protection, and they might be designated $B2_t$ in equation 1, as they would be for a private company. But when taking the national perspective, these grants are costs, and would properly be designated as $C2_t$ or I in equation 1.

Private companies that buy insurance have a certain cost for insurance, as reflected in $C3_t$. They might also self-insure by having a sinking fund for covering uncertain costs. Insurance premiums raise LCC, and insurance proceeds (i.e., $B3_t$) reduce LCC. Governments, on the other hand, generally do not buy insurance or put money aside specifically for self insurance.

PROPOSED SOFTWARE TOOL AND IMPACTS

Equations 1 and 2 are not difficult to understand or use. The data needed to implement them in decision-making, however, are difficult to produce. For example, the expected value of loss reductions from an investment in terrorist protection requires data resources as well as the ability to use mathematics and statistics to convert uncertain benefits and costs to time equivalent expected values or cumulative probability distributions. A user-friendly, decision-support software tool is proposed that will help facility managers maximize the likely reduction in terrorist-related damages when choosing among alternative protective investments. The tool must support LCC and NS computations based on point estimates as well as probability distributions. It must account for insurance and incentives as well as the reductions in losses and costs from alternative approaches to protection. It must account for non-terrorist related benefits that spillover from terrorist protection. It must apply to public and private investments. It must encompass both existing and new structures. And it must be flexible to account for multiyear investments spread over time. Finally, the tool must be in a format that will run on most computers, and it must have a graphical interface that will encourage facility managers to use it.[1]

Significant impacts are expected from such a software product. The widely available tool will encourage facility managers and designers to consider in a fiscally-responsible manner terrorist protective investments in more structures than if the software were unavailable. Favorable economic evaluations of protective investments will encourage budget approval and implementation of more protection. The expected economic impacts will be a decrease in the expected value of terrorist-induced losses (i.e., a decrease in deaths, injuries and damages from terrorist attacks) and a decrease in damages and injuries stemming from other disasters that affect buildings—fire, floods, and high winds.

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ACKNOWLEDGMENTS

Special appreciation is due Dr. Robert Chapman and Dr. Stephen Weber for their technical contributions; Ms. Christine Izzo for her assistance in data collection; and Ms. J'aime Maynard for preparing the final manuscript.

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[1] The proposed tool is under development in the Building and Fire Research Laboratory at the National Institute of Standards and Technology, Gaithersburg MD, USA, under the direction of Dr. Robert Chapman.